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EPA

SITE Technology Capsule
InPlant Systems, Inc. SFC 0.5 Oleofiltration System

Introduction

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, committed to protecting human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. SARA mandates the implementation of permanent solutions and the use of alternative treatment technologies or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and Federal agencies, as well as private parties, are now exploring a growing number of innovative technologies for treating hazardous wastes. The sites on the National Priorities List total over 1,200 and comprise a broad spectrum of physical, chemical, and environmental conditions requiring varying types of remediation. The U.S. Environmental Protection Agency (EPA) has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies to Superfund sites. One such initiative is EPA's Superfund Innovative Technology Evaluation (SITE) Program, which was established to accelerate development, demonstration, and use of innovative technologies for site cleanups. EPA SITE Technology Capsules summarize the latest information available on selected innovative treatment and site remediation technologies and related issues. These capsules are designed to help EPA remedial project managers, EPA on-scene coordinators, contractors, and other site cleanup managers understand the types of data and site characteristics needed to effectively evaluate a technology's applicability for cleaning up Superfund sites.

This Capsule provides information on the InPlant Systems, Inc. (InPlant) Oleofiltration technology, a technology developed to separate suspended, emulsified, and a portion of dissolved hydrocarbons from water. The Oleofiltration technology was evaluated under EPA's SITE Demonstration Program at a former oil reprocessing facility in June 1994. This Capsule presents the following information:

- Abstract
- Technology Description
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- Site Requirements
- Performance Data
- Technology Status
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Abstract

Oleofiltration is an innovative hydrocarbon recovery technology that utilizes amine-coated, oleophilic granules to separate suspended and mechanically emulsified hydrocarbons from aqueous solutions. The granules are also reported to separate several types of chemical emulsions and to reduce concentrations of dissolved hydrocarbons. The technology was developed by Exxon Research and Engineering Company and manufactured under exclusive license and patent by InPlant of Houston, Texas. North

SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

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American Technologies Group, Inc. (NATGI) is the sole marketer of the technology.

The InPlant SFC System combines an innovative, vertical-fin, coalescing separator and a patented, amine-coated, ceramic granule filtration system (the Oleofilter) into one unit, capable, according to InPlant, of treating virtually any insoluble hydrocarbon/water mixture. When the hydrocarbon/water mixture entering the granules contains less than 500 milligrams/liter (mg/L) of total recoverable petroleum hydrocarbons (TRPH) and less than 50 mg/L of suspended solids, InPlant claims that the SFC System will produce a treated water effluent that contains 15 mg/L or less of TRPH. SFC Systems operate at atmospheric pressure and are available in sizes capable of treating 2.2 to 44 gallons per minute (gpm). For treatment of larger flow rates (up to 1,000 gpm), the coalescing unit is manufactured as a separate stand-alone component from the Oleofilter. The Oleofilters designed to treat larger flow rates operate under low pressure [less than 30 pounds per square inch (psi)]. The units can be operated independently or installed in series on a single skid. The latter configuration provides the same treatment capabilities as the SFC System.

The SFC 0.5 System was evaluated under the EPA SITE Demonstration Program at a former oil reprocessing facility in Pembroke Park, Florida.; This Superfund site has a layer of free product (waste oil) floating on groundwater that is contaminated with a variety of organic and inorganic constituents. Demonstration activities were initiated on June 2, 1994 and were concluded on June 18, 1994. The SFC 0.5 System has a treatment capacity of 2.2 gpm. The waste oil recovered for the demonstration was significantly more viscous than the oil collected for the pre-demonstration treatabillty study. Consequently, the feed stream to the SFC System was thinned with virgin, lighter weight motor oil and then emulsified with site groundwater using an air-powered inline blender. The unit was evaluated over five separate operating cycles (“runs”). The feed stream was the same for all runs except Run 4. The feed stream for Run 4 was a 3-to-1 mixture of thinned oil to kerosene emulsified in groundwater. The TRPH concentration in the feed stream **for** Run 4 was two to five times higher than the concentrations for the other runs. These differences in Run 4 were implemented in an attempt to resolve filter backflushing difficulties associated with treating a very viscous oil.

The first critical objective of the demonstration was to evaluate whether the SFC System could remove at least 90 percent of the TRPH from the emulsified oil/water influent stream. Data indicate that the SFC System met this goal for all runs except Run 4.

The second critical objective was to determine whether the SFC System could reduce TRPH concentrations in the treated water exiting the system to 15 mg/L or less. When data are combined and evaluated for the runs where the system operated within normal design parameters (Runs 1 and 5) this goal was met. For the other runs, the 15 mg/L threshold was exceeded.

The third critical objective was to evaluate the effectiveness of the oleophilic granules by comparing the TRPH concentration in the oil/water emulsion before and after passing through the granules. Combined data for the runs with similar feed streams (Runs 1, 2, 3, and 5) show the granules achieved a 95 percent reduction in TRPH concentration. A 65 percent reduction in TRPH was obtained in Run 4.

Several noncritical objectives were evaluated for the demonstration. One of these objectives was evaluation of the relative effectiveness of the SFC System hydrocarbon-capturing components. Results indicate that the coalescing separator accounted for 45 to 62 percent of the total TRPH removed; the oleophilic granules removed the corresponding 55 to 38 percent.

Another noncritical objective was to evaluate the ability of the SFC System to remove suspended solids (measured as non-filterable residue, NFR) from the oil/water influent. NFR removal ranged from 27 percent to 58 percent; NFR values in the oil/water influent were generally below 50 mg/L.

The ability of the SFC System to remove selected semivolatile organic compounds (SVOCs) was another noncritical objective. SVOC concentrations in the oil/water influent for Runs 1, 2, 3, and 5 were too low to support any conclusions about removal effectiveness. Run 4 had higher SVOC concentrations in the oil/water influent. For this run, 75 percent removal of naphthalene and 81 percent removal of 2-methyfnaphthalene were achieved.

During the demonstration, the SFC System did not achieve steady-state operating conditions. The lack of steady-state conditions apparently resulted from treating the unexpectedly high-viscosity oil during a short-duration evaluation of the technology. This situation precluded the evaluation of two noncritical objectives. An evaluation of the effectiveness of the coalescing separator at segregating oil from water, as determined by the percent water in the concentrated oil effluent, could not be made since the increased agitation that occurred during backflushing resulted in overflowing of backflushing water into the concentrated oil effluent stream. An acceptable materials mass balance closure could not be achieved since the amount of oil retained in the unit was not constant across the runs.

Technology Description

SFC systems, which contain only one internal moving part (a liquid-level control float), are designed to be explosion-proof and are operated at atmospheric pressure. Figure **1** shows the configuration and cross-sectional view of the liquid flow through the SFC 0.5 System. The hydrocarbon/water mixture (oil/water influent stream) feeds into the top of the unit through Port A, moves downward inside the outer shell, and flows upward past the vertical-fin coalescing separator. Free-floating and emulsified hydrocarbons passing over the coalescing fins combine with droplets already adsorbed on the fins' surface.

The hydrocarbon droplets continue to increase in size until the buoyancy of the droplets overcomes the adsorptive forces. The droplets then release from the fins, float toward the top of the unit, and are discharged from the system through Port B as the concentrated oil effluent stream. Final hydrocarbon filtration occurs as the remaining emulsified and dissolved hydrocarbons flow upward through the center of the unit and gravity flow through the bed of amine-coated, oleophilic granules. The majority of remaining hydrocarbons attach to the granules, and the treated water (treated water effluent stream) exits the system through Port C.

When the Oleofilter becomes saturated with hydrocarbons and suspended solids (InPlant states that **15** to 20 liters of hydrocarbons can be retained by 100 liters of oleophilic granules), the granule bed regenerates itself automatically by backflushing. Back-flushing is activated when the system reaches a set pressure differential across the bed. The pressure drop that initiates backflushing can be adjusted by the operator to optimize filtration time, while preventing filter breakthrough.

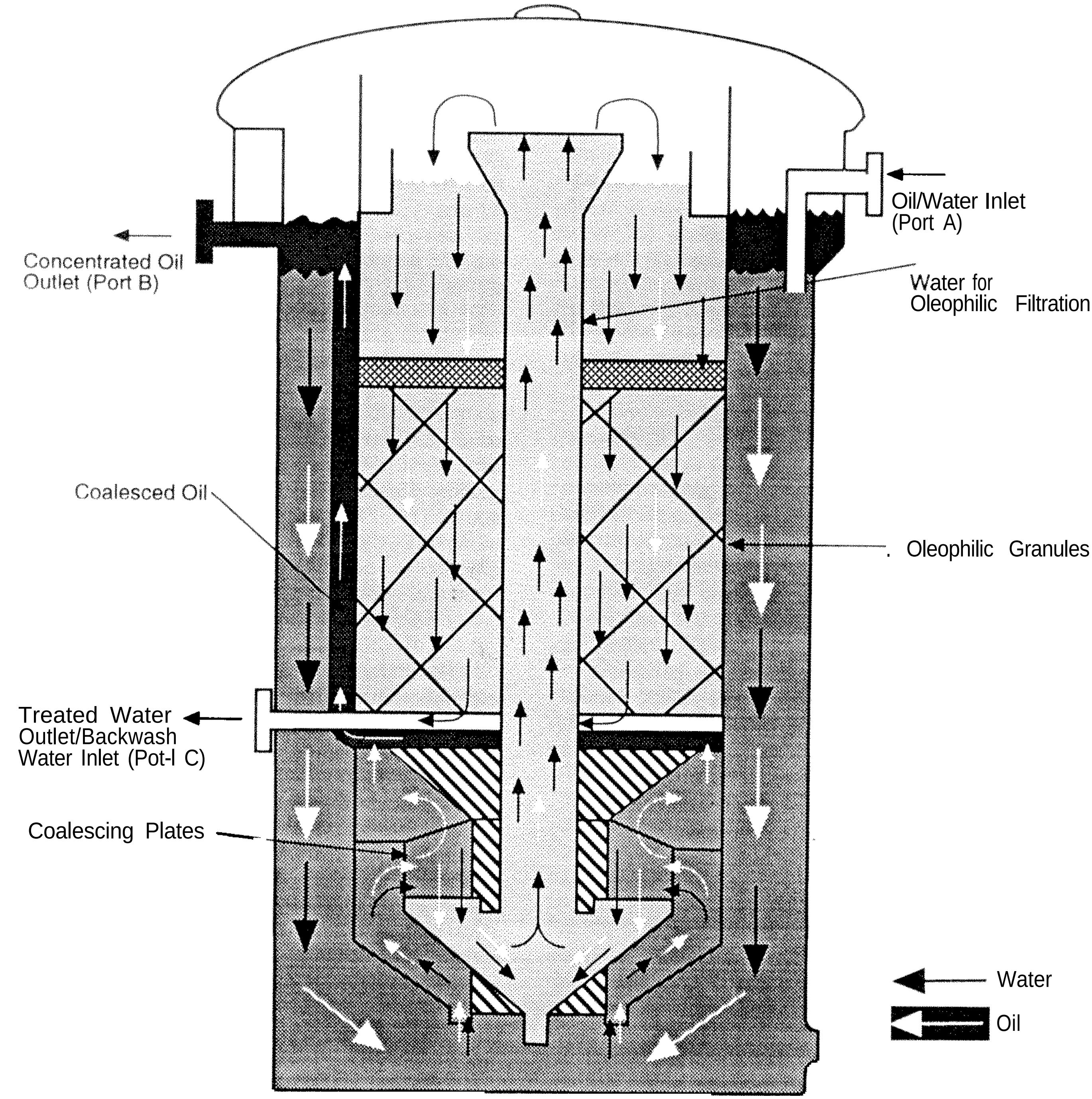
The backflush cycle takes 20 minutes. Water for backflushing is pumped into the bottom of the system through Port C. During the first 4 minutes of the backflush cycle, only water is introduced. During the next 8 minutes, both air (supplied by an external compressor) and water are flushed through the filter. The air increases the agitation that physically strips the hydrocarbons from the granules. During the last 8 minutes of the backfiush cycle, a water only rinse is performed. The backflush water flow rate is equal to the nominal throughput of the filter **(2.2** gpm for the SFC 0.5 System), and the air flow rate is 0.3 standard cubic feet per minute (scfm) per gpm of water flow (0.66 scfm for the SFC 0.5 System). Therefore, the amount of air exiting the SFC 0.5 System during backflushing is approximately 5 scf. The hydrocarbon/water mixture generated during backflushing (backflush water effluent stream) gravity flows from Port D near the top of the unit (not shown in Figure 1) to a sump or holding tank. The coalesced hydrocarbons within the mixture typically separate within 10 to 30 minutes and can be reprocessed through the SFC System, leaving only the concentrated hydrocarbons to be recycled or disposed of.

Although the design of the vertical-fin coalescing separator within the SFC System is novel, the amine-coated oleophilic granules are the innovative component of the system. The granules separate emulsions not treatable by conventional oil/water separators. The oleophilic granules use a montmorillonite (clay) base that has been heated to 800°C **[1]*.** The high temperature decomposes the montmorillonite into an aluminum silicate that assumes a crystalline, ceramic structure. The aluminum silicate is then crushed into granules with diameters between 0.6 and 1 millimeter.

The granules are subsequently treated to attach the oleophilic amine (see Figure 2). Through a series of substitution reactions, an amine molecule bonds to a silica atom, leaving a long hydrophobic (and oleophilic) chain **($C_{18}H_{33}$)** to which hydrocarbons are attracted [2, pp. **15-16].** As the **filtration process continues, hydrocarbons** flowing past the granules agglomerate with the amine-attracted hydrocarbons, forming droplets. The hydrocarbons remain attached to the amine, while the separated water exits the system. The magnitude of hydrocarbon uptake is inversely proportional to the compounds' solubility in water and is controlled by a partitioning process [3, p. 2054].

During backflushing, the hydrocarbon droplets and hydrocarbon-laden solids are physically stripped from the amines and, along with other entrained solids, exit the unit with the back-flushing water. The hydrocarbons in the backflushing water are predominantly coalesced and now can be removed by conventional oil/water separation techniques. InPlant has installed several systems where the hydrocarbon/

*[Reference Number, Page Number]



Note: The backwash water outlet (Port D) is not shown in this view.
Source: Adapted from SFC 0.5x Operating Manual, 1992.

Figure 1. SFC 0.5 Oleofiltration System Configuration.

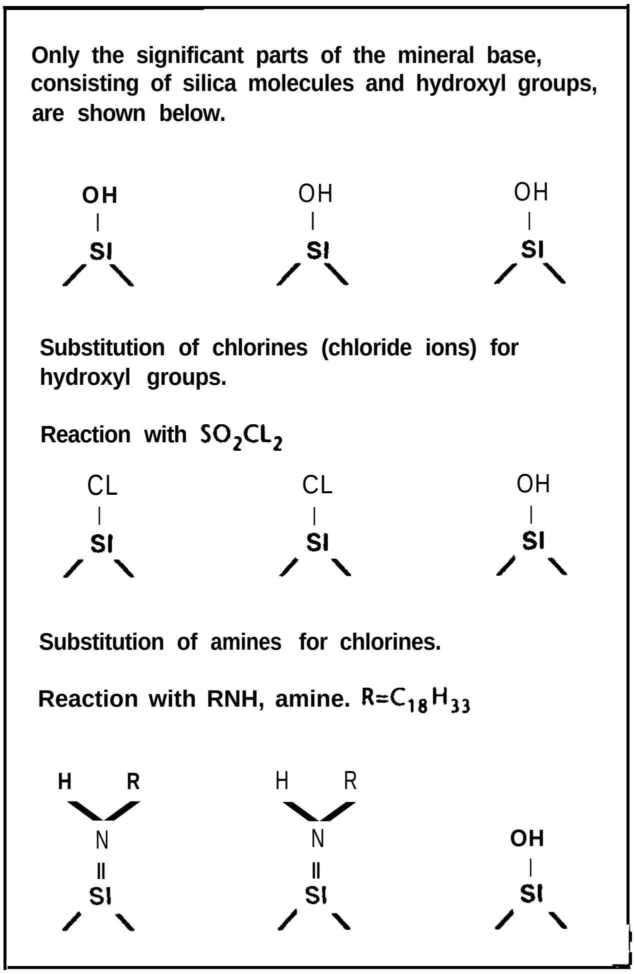


Figure 2. Generation of oleophilic amine-coated granules. Source: [2]

water mixture from backflushing is fed back into the system, and the coalesced hydrocarbons are removed by the vertical-fin coalescing separator. Any emulsified hydrocarbons are captured by the oleophilic granules. This approach eliminates the need for disposal of the hydrocarbon/water mixture resulting from backflushing.

Technology Applicability

The SFC System is reportedly capable of treating virtually an insoluble hydrocarbon/water mixture. The stated advantage of this technology over other oil/water separation techniques is its ability to separate mechanical and several types of chemical emulsions. InPlant claims that the SFC System can remove TRPH from hydrocarbon/water emulsions to levels below 15 mg/L when the emulsion reaching the granules contains less than 500 mg/L TRPH and less than 50 mg/L of suspended solids. According to InPlant, the amine-coated granules have been proven effective on a wide variety of hydrocarbons including gasoline; crude oil; diesel; benzene, toluene, ethylbenzene, and xylene (BTEX) compounds; and polynuclear aromatic hydrocarbons (PAHs). The granules reportedly also remove chlorinated hydrocarbons such as pentachlorophenol (PCP), polychlorinated biphenyls (PCBs), and trichloroethane (TCA), as well as vegetable and animal oils.

The ability of the oleophilic granules to separate hydrocarbon/water emulsions and reduce dissolved hydrocarbon concentrations to levels consistent with other secondary treatment systems indicates the potential for the SFC System to be used in conjunction with other treatment technologies. Site remediation techniques, such as steam injection-vapor extraction and soil flushing, can generate hydrocarbon/water emulsions that must be treated. Pumps used in transferring oily water also can produce emulsions that must be separated prior to further treatment. The SFC System can be employed in these and other applications including the remediation of contaminated groundwater, in-process oil/water separation, wastewater filtration, onsite waste reduction and recovery, and bilge and ballast water treatment.

When used as a component of a treatment train, the technology can significantly reduce hydrocarbon loading to other downstream treatment equipment such as air strippers and carbon filtration units. This reduced loading results in increased on-line time and decreased operating and maintenance costs for the treatment train. Depending on local pretreatment standards, treated water exiting the SFC System may be acceptable for introduction to the sanitary sewer system without further treatment.

Table 1 addresses the performance of the SFC System based upon the nine evaluation criteria used for decision-making in the Superfund feasibility study (FS) process. If the SFC System is used as a component in a treatment train, evaluation of the entire train also should be performed.

Technology Limitations

The Oleofiltration technology concentrates contaminants by separating free, emulsified, and some dissolved hydrocarbons from water. Although the toxicity of the water phase decreases, the toxicity and mobility of the concentrated hydrocarbons are unchanged. The concentrated hydrocarbons must then be further treated or disposed. Even under ideal conditions, the treated water typically will contain between 4 and 15 mg/L of TRPH, requiring further treatment prior to release at some sites.

Although the oleophilic granules are relatively durable, collision between granules during filtration and

Table 1. Nine Evaluation Criteria for the SFC System

Evaluation Criteria	Performance
Overall Protection of Human Health and the Environment	• Provides both short-term and long-term protection by reducing contaminants in groundwater. • Prevents further groundwater contamination and offsite migration caused by emissions during treatment. • Demonstrated capability of reducing TRPH concentrations in oil/water mixtures to 15 mg/L. • Concentrates but does not destroy contaminants.
Compliance with Federal applicable or relevant and appropriate requirements (ARARs)	• Effluent needs to be treated further to meet Federal Drinking Water Standards if it is to be re-injected directly into the ground. • Effluent may meet pretreatment standards for release to the local publicly-owned treatment plant (POTW). • May have to meet substantive requirements of a Resource Conservation and Recovery Act (RCRA) treatment permit if treating hazardous wastes. • May have to meet substantive requirements of a Clean Air Act (CAA) permit for air discharge during back-flushing if volatile organic compounds (VOCs) are present. • Concentrated oil effluent may be regulated under the Toxic Substances Control Act (TSCA) if polychlorinated biphenyls (PCBs) are present.
Long-Term Effectiveness and Performance	• Residuals treatment or recycling may be required (effluent water, concentrated oil, oily water from backflushing).
Reduction of Toxicity, Mobility, or Volume through Treatment	• The technology concentrates contaminants, reducing waste volume, but does not change the contaminants' mobility or toxicity.
Short-Term Effectiveness	• Community and workers will be protected because the system is almost entirely self-contained.
Implementability	• Most systems are shipped pre-assembled or as modules that are easily connected. • Pretreatment of feed stream is typically not required. • System is explosion-proof. • If VOCs are present, a release (5 to 106 scfm) of contaminated air will occur during backfiushing. • Additional treatment options may be needed for residuals. • Oleophilic granules usage life is shortened if treating solutions with pH > 10.5 (granules become brittle) or chlorinated solvents with concentrations > 100 mg/L (weakens amine bonds). • Backflush initiation needs to be adjusted, If treating oils of various viscosities, to prevent breakthrough prior to backflushing.
Cost	• The cost to remediate 50 million gallons of contaminated groundwater (22-gpm system with 95% on-line time) is approximately $2.57 per thousand gallons.
State Acceptance	• Since this system will most often be used as a component in a treatment train, acceptance is tied to overall treatment acceptability.
Community Acceptance	• Should be generally acceptable to the public since emissions during treatment are minimal.

backflushing results in breakage. Broken granules that are small enough to pass through the retention screen are discharged from the system during backflushing. Assuming a back-flush frequency of every 10 hours, InPlant states that approximately 8 percent of the granules must be replaced every 12 months of operation.

InPlant reports that the oleophilic granules are sensitive to two chemical conditions, both of which shorten the operational life of the granules. Treatment of solutions having a pH greater than 10.5 for extended periods of time makes the granules more brittle. The increased breakage caused by this condition is estimated to be an additional 4 percent every 12 months of operation. Treatment of solutions with chlorinated solvents present in concentrations greater than 100 mg/L weakens the amine bonds. A similar attrition rate (an additional 4 percent every 12 months) is reportedly caused by prolonged treatment of these solutions.

The SFC System is reportedly less effective in treating chemical emulsions containing anionic surfactants than other types. Anionic surfactants affect the ability of the granules' amine coating to attract and retain hydrocarbons. InPlant states that use of SFC Systems for the treatment of hydrocarbon/water emulsions created by anionic surfactants resulted in TRPH concentrations in the treated water of 50 to 80 mg/L. Although not evaluated during the SITE demonstration, the granules reportedly are more effective at removing hydrocarbons from chemical emulsions containing cationic or nonionic surfactants.

Although the SFC System appears to effectively treat oils of varying viscosities and densities, adjustments to the backflushing cycle must be made to reduce the amount of operator oversight required. The pressure at which the backflushing cycle is initiated must be adjusted to maximize filtration time while preventing breakthrough of the hydrocarbons prior to backflushing. During the SITE demonstration, the SFC System apparently exhibited breakthrough prior to backflushing when a kerosene and oil mixture was used as the feed oil. InPlant reportedly has implemented modifications to the system that allow in-field adjustment of the pressure at which backflushing is initiated. These modifications, combined with periodic monitoring of system performance, should eliminate the difficulties.

Treatment of high viscosity oils may foul the granules, preventing effective backflushing. InPlant claims that the use of hot water for backflushing or the addition of a steam coil attachment to the system will reduce the viscosity of most retained oils and allow normal backflushing. During the SITE demonstration, all but one of the runs used a very **viscous oil that had been thinned with virgin motor** oil. Performance of Runs 1, 2, and 3 resulted in fouling of the granules, which had to be removed, washed in mineral spirits, and reinstalled. Subsequent use of the hot water (approximately 200 ^{0}F) increased the effectiveness of the backflushing. Treatability studies encompassing the full range of oil properties at a site, along with provisions for hot water backflushing, if indicated, should resolve backflushing difficulties.

According to InPlant, when the TRPH concentration in the pre-granule water exceeds 500 mg/L, the TRPH concentration in the treated water effluent may exceed 15 mg/L. Run 4 of the demonstration had an average TRPH concentration in the pre-granule water of 1,242 mg/L. The treated water effluent contained an average concentration of 39 mg/L (these averages do not include concentrations measured after filter breakthrough). This reduction represents a 97 percent removal of TRPH. Pilot-scale treatability testing prior to full-scale implementation should determine the ability of the unit to meet **site-specific performance goals.**

Process Residuals

The SFC System generates three process streams: treated water, concentrated contaminants (during the demonstration this wastestream was a concentrated waste oil), and hydrocarbon-laden water from backflushing. Additionally, if the feed stream contains volatile organic compounds (VOCs), air emissions will be generated during backfiushing. Under optimum conditions, the treated water will reportedly contain between 4 and 15 mg/L of TRPH. Therefore, this process stream may need to be further treated with a tertiary process onsite or transported offsite for further treatment. The concentrated hydrocarbon effluent stream can be transported and disposed of offsite. If the concentrated hydrocarbon is waste oil and meets the waste oil specifications of 40 CFR 279, it can be used as fuel. Two options exist for the water from backflushing. This water can be fed back into the system where the coalesced hydrocarbons will be removed and the water filtered. Alternately, the water from back-flushing can be transported offsite for treatment and disposal.

Depending on the size of the SFC System, air emissions during backflushing range from 5 to 106 scf. If the feed stream contains VOCs, a percentage of them will become entrained in the backflushing air and exit through the top of the system. Depending on the types and concentrations of VOCs and applicable regulations,

emissions controls such as carbon filters may be required.

Site Requirements

Site requirements for the operation of the SFC System include a level area, electricity, water, and compressed air. The SFC System must be operated on a level, non-shifting surface. A 9-square-yard pad of 6-inch reinforced concrete will support the largest SFC units. Additional space for storage of backflush influent and effluent water must be available. If potable water is used for backflushing, water lines or a service for filling the water tank between back-flushes must be available. A water tank, with capacity in excess of the backflush volume, must be provided. Storage capacity for the concentrated hydrocarbons and treated water must be available (if the water is not being treated or discharged immediately). Electrical power, consisting of 4 kilovolt-amp (kVA), 460/230-volt. 3-phase service must be available to operate the largest SFC Systems. Smaller systems require 40-amp, 220-volt service. Alternately, electrical power could be supplied by an onsite mobile generator.

Current designs of the SFC System use pneumatic controllers, requiring approximately 0.5 scfm of compressed air. Additionally, the back-flushing cycle requires compressed air to increase agitation of the granules. A source of compressed air capable of producing a volumetric flow rate of 15 scfm and a minimum air pressure of 100 psi will supply sufficient air for both purposes on any size SFC System. InPlant has recently begun replacing pneumatic controllers with programmable logic controllers on SFC Systems.

Depending on the viscosity of the oil, hot water or steam may be required for effective backflushing. A portable hot water washer or steam generator therefore may be required.

Performance Data

The SFC Oleofiltration System was accepted into the SITE Demonstration Program in December 1992. The Petroleum Products Corporation (PPC) Superfund site in Pembroke Park, Florida was chosen as the demonstration site. Accidental releases during the operation of this former oil reprocessing facility resulted in the deposition of approximately 29,000 gallons of free product (waste oil) on the groundwater surface. The groundwater underneath the oil is contaminated with a variety of organic and inorganic constituents.

Prior to the demonstration, samples of oil from the site were sent to NATGI for treatability studies. Aliquots of the oil were combined with different volumes of water, mixed with a blender, and poured through separatory funnels containing oleophilic granules. Samples of the water **exiting the funnels were analyzed for oil and grease by** NATGI using EPA Method 413.1 [4]. Results of the study, presented In Table 2, showed the granules to be effective at removing oil and grease from the oil/water emulsions.

Table 2. NATGI Treatability Study Results

Six one liter samples of groundwater were contaminated with 20, 100, 300, 500, 2,000, and 10,000 mg/L of oil respectively, mechanically emulsified with a high-speed mixer for 1 minute, and manually poured into separatory funnels containing approximately 0.5 liter of amine-coated ceramic granules. The effluent (output) was analyzed for Oil and Grease using EPA Method 413.1.[4]

Input (mg/L)	output (mg/L)	Percent Removal (mg/L)
20	2.5	87.5
100	4.0	96.0
300	5.0	98.3
500	3.1	99.4
2,000	3.6	99.8
10,000	2.5	99.9

The SFC 0.5 Oleofiltration System (2.2 gpm) was evaluated during the SITE demonstration in June 1994 at the PPC site. Since the site did not have significant amounts of oil emulsified in water, an artificial feed, consisting of recovered waste oil emulsified in the contaminated groundwater, was formulated to test the system. The contaminated groundwater was obtained by diverting a small stream from the site's full-scale remediation system. This groundwater feed exited the bottom of the full-scale oil/water separator, passed through a flow meter, and entered an air-powered inline blender used to create the emulsion to be used in the demonstration.

The feed oil was collected from a sump where the viscous oil had risen to the surface. Approximately 30 gallons of highly viscous oil were mixed with 15 gallons of 10W-30-weight motor oil to reduce the viscosity of the oil. The mixed oil had an average viscosity of 56.3 centistokes (cs). A peristaltic pump was used to deliver the oil through a feed line to the inline blender. The inline blender then created the oil/water emulsion that was fed into the system. After passing through the SFC System, the treated water effluent was returned to the full-scale oil/water separator. Although the SFC System was reportedly capable of reprocessing the oil/water mixture resulting from backfiushing, the water layer from backflushing was returned to the full-scale oil/water separator. The concentrated oil effluent and the oil layer from backffushing were stored in drums for offsite disposal.

Samples were collected from the groundwater feed, oil feed, emulsified oil/water influent, water prior to entering the granules (pre-granule water), treated water effluent, backflushing effluent, and concentrated oil effluent.

The demonstration consisted of five separate runs. Runs 1, 2, 3, and 5 used the mixed feed oil. Run 4 used a 3-to-1 mixture of the previously mixed oil to kerosene. The feed oil for Run 4 had an average viscosity of 30.1 cs. Samples were collected for TRPH analysis using EPA Method 418.1 [4]. Additional samples were collected and analyzed for NFR. SVOCs, and percent water using EPA Method 160.2 [4], EPA Method 8270 [5], and ASTM Method D95-83 [6]. The average TRPH concentrations for the oil/water influents ranged from 322 to 2,802 mg/L.

Due to operational difficulties associated with filter backflushing, only one complete run (Run 1) was accomplished. Runs 2 and 3 were shortened because the backflushing cycle preceding each run did not clean the granules sufficiently to allow the pressure differential across the granule bed to reset to InPlant's specifications of zero inches of mercury (in. Hg). The back-flush triggering pressure of 16 in. Hg was consequently reached sooner. The operational difficulties were apparently caused by the high viscosity and solids content of the feed oil, which were different from the oil provided to InPlant for the treatability studies. InPlant claims that adjustments prior to unit delivery and the addition of a steam coil attachment would have resolved the difficulties.

Run 4 was terminated when visible oil appeared in the treated water effluent. Analytical results confirmed that filter breakthrough had occurred. Run 5 was terminated when the level of pre-granule water in the unit had risen to the height where it was discharging through the backflush water outlet. Additionally, it was thought that visible oil appeared again in the treated water effluent (analytical results indicated that this conclusion was inaccurate). Table 3 presents TRPH results for the oil/water influent, pre-granule water, and treated water effluent for all five runs. Table 4 presents results for NFR, naphthalene, and 2-methylnaphthalene for the oil/water influent and treated water effluent. Results from the first sample collected in each run have not been presented since the collection time (t = 10 minutes) was less than the calculated residence time of the unit (i.e., water entering the unit at initiation of the run had not yet reached the treated water sample port). Table 5 presents a summary of project objectives, results, and conclusions for the demonstration.

Due to operational differences among some of the runs, demonstration data have been evaluated using several scenarios. Since Runs 1, 2, 3, and 5 used the same feed oil, data from these runs were pooled and evaluated together. Within this group, only Runs 1 and 5 were initiated with the granules backflushed sufficiently for the initial pressure differential across the granule bed to approach InPlant's specification of zero in. Hg. Consequently, evaluation of demonstration objectives state a result for the pooled data from Runs 1, 2, 3, and 5 (13 data points), and a result for the pooled data from Runs 1 and 5 only (8 data points).

Since Run 4 used a different type of feed oil and oil feed rate, data from this run were evaluated separately. During this run, the concentration of TRPH present in the pre-granule water exceeded InPlant's stated limitation of 500 mg/L. Consequently, the demonstration objective of achieving 15 mg/L or less in the treated water effluent was not evaluated. Additionally, InPlant claims that the pressure differential across the granule bed at which backflushing was triggered (16 in. Hg) was set to accommodate the 500 mg/L maximum TRPH concentration, and the higher concentration was responsible for the apparent filter breakthrough. Accordingly, Run 4 was evaluated using the data for the entire run (5 data points) and also using only the data prior to filter breakthrough (3 data points).

The SFC System did not achieve steady-state operating conditions during the demonstration. This situation precluded the evaluation of two noncritical objectives. An evaluation of the effectiveness of the coalescing separator at segregating oil from water, as determined by the percent water in the concentrated oil effluent, could not be made since the increased agitation that occurred during backflushing resulted in overflowing of backflushing water into the concentrated oil effluent stream. An acceptable materials mass balance closure could not be achieved since the amount of oil retained in the unit was not constant across the runs.

InPlant has provided performance data from a bench-scale study of the ability of the oleophilic granules to remove TRPH, BTEX, and PAHs [7]. The study, conducted on tank water bottoms from a condensate tank at a bulk petroleum storage and transfer facility in The Netherlands, achieved petroleum hydro-carbon concentrations in the outlet samples of 1.43 and 2.49 mg/L for times t= 10 minutes and t= 105

Table 3. Summary of TRPH Analyses

Run	Elasped Time (min)	Influent Concentration (mg/L)	Pre-granule Concentration (mg/L)	Effluent Concentration (mg/L)
1	60	842	691	29.4
1	120	989	499	20.3
1	180	1240	651	13.8
1	240	1120	445	10.9
1	300	1170	487	17.4
2	30	366	301	16.8
2	60	322	227	32.2
2	90	484	261	25.7
3	20	988	386	25.0
3	40	981	137	20.7
4	45	1991	1260	43.3
4	90	2680	997	26.7
4	135	2004	1470	47.5
4	180	2802	1302	484
4	240	1630	955	1470
5	45	681	456	17.2
5	75	NA	351	14.7
5	105	565	191	7.4
5	135	2448	189	10.1

NA - Not analyzed by laboratory.

Table 4. Summary of NFR and Specific SVOC Analyses

Run	Influent NFR (mg/L)	Effluent NFR (mg/L)	Influent Naphthalene (µg/L)	Effluent Naphthalene (µg/L)	Influent 2-Methylnaphthalene (µg/L)	Effluent 2-Methylnaphthalene (µg/L)
1	19	14	13	10 u	11	10 u
1	11	6	***	***	***	• **
1	18	7	12	10 u	10	10 u
1	24	6	***	***	***	***
1	20	11	6j	10 u	5j	10 u
2	30	14	12	10 u	7 j	10 u
2	23	14	***	***	***	• **
2	26	13	12	10 u	7j	10 u
3	31	10	13	10 u	7j	10 u
3	37	16	***	• ***	***	•***
4	32	17	210	10 u	320	10 u
4	19	29	***	***	***	***
4	40	20	250	25	410	21
4	34	21	***	***	***	• **
4	24	12	100	90	140	130
5	29	9	39 j	20	38 j	14
5	22	9	***	***	***	• **
5	23	9	20	10 u	15	10 u
5	20	6	***	***	***	• **

u below detection limits
j estimated value
*** no sample collected

Table 5. Summary of Project Objectives, Results, and Conclusions

Objective	Results[1]	Conclusions
Critical Obisctives		
Evaluate claim of 96% minimum removal of TRPH[2] from oil/water emulsion.	The overall TRPH removals were: 98% - Runs 1,2,3, and 5 (98% - Runs 1 and 5 only) 81% - Run 4, all data (98% - Run 4, data prior to breakthrough)	Runs 1,2,3, and 5 met the objective. Runs 1 and 5 met the objective. Overall objective not met for Run 4 using all data. Objective met for Run 4 using data prior to breakthrough.
Evaluate claim of 15 mg/L maximum TRPH concentration in effluent. (Test hypothesis that sample mean is not statistically significant from 15 mg/L at the 96% confidence interval.)	The average effluent concentrations were: 18.7 mg/L - Runs 1,2,3, and 5 (15.7 mg/L - Runs 1 and 5) 414.3 mg/L - Run 4, all data (39.2 mg/L - Run 4, data prior to breakthrough)	The average of Runs 1, 2, 3, and 5 is statistically different from the objective. The average of Runs 1 and 5 is not statistically different from the objective. For Run 4, the TRPH concentration in the pre-granule water exceeded the developer's stated limits. Therefore, no conclusions about this objective are stated for Run 4.
Determine TRPH removal effectiveness of oleophilic granules.	The TRPH removals of granules were: 95% - Runs 1,2,3, and 5 (96% - Runs 1 and 5) 65% - Run 4, all data (97% Run 4, data prior to breakthrough)	The granules were able to significantly reduce TRPH concentrations.
Noncritical Objectives		
Determine the relative contributions to TRPH removal of the coalescing unit and oleophilic granules, (Determine percentage of total TRPH removal accomplished by the coalescing unit and by granules.)	The TRPH removals for coalescing unit: 61% - Runs 1,2,3, and 5 (62% - Runs 1 and 5) 57% -Run 4, all data (45% - Run 4, data prior to breakthrough) The TRPH removals for granules were: 39% - Runs 1,2,3, and 5 (38% - Runs 1 and 5) 43% - Run 4, all data (55% - Run 4, data prior to breakthrough)	For Runs 1, 2, 3, and 5, the coalescing unit removed more TRPH than the granules by a factor of 1.56. For Runs 1 and 5, the coalescing unit removed more TRPH than the granules by a factor of 1.63. For Run 4 using all data, the coalescing unit removed more TRPH than the granules by a factor of 1.32. For Run 4 prior to breakthrough, the granules removed more TRPH than the coalescing unit by a factor of 1.22.
Evaluate the SFG System's ability to remove suspended solids from the oil/water influent.	The NFR[3] removals were: 57% - Runs 1,2,3, and 5 (58% - Runs 1 and 5) 34% - Run 4, all data (27% - Run 4, data prior to breakthrough)	For Runs 1,2,3, and 5 and Runs 1 and 5, the NFR removal was significant. The NFR removal was less for Run 4 using all data and for Run 4 using data prior to breakthrough.
Examine the difference in % moisture between feed oil and oil effluent.	Could not be evaluated as system did not reach steady-state conditions during demonstration.	No conclusions can be made regarding the ability of the coalescing unit to produce a low-moisture, concentrated oil stream.
Evaluate the ability of the SFC System to remove naphthalene, 2-methylnaphthalene and 1,2-dichlorobenzene.	The SVOC[4] removals were: 75% - Naphthalene for Run 4, all data 81% - 2-Methylnaphthalene for Run 4, all data	No conclusions can be made regarding the removal of specific SVOCs for Runs 1, 2, 3, and 5 due to low influent concentrations. The SFC System significantly removed both naphthalene and 2-methyfnaphthalene during Run 4. (1,2-dichlorobenzene was not present above detection limit.)
Determine whether mass balance closures of 80 to 120% can be achieved for TRPH and total materials.	Mass balance closures were not possible due to lack of steady-state conditions.	No conclusions can be made regarding either TRPH or total mass balance closure.
Establish a +50 to -30% treatment cost estimate	Cost for treating 50,000,000 gallons of water (95% on-line time) is $2.57 per 1,000 gallons	Cost estimates are highly dependent on site-specific factors. Actual costs may vary significantly.

1 Indlcated results obtained by combining data from specified Runs (e.g., "Runs 1 and 5" Indicates data pooled from those Runs only)
2 TRPH total recoverable petroleum hydrocarbons (EPA Method 418.1)
3 NFR Is non-filterable residue (a measure of suspended solids)
4 SVOC Is semivolatile organic compound

minutes, respectively. The study also indicated effective **removal of** PAHs but less effective removal of BTEX.

Technology Status

The SFC System is currently being used in industrial applications including:

- Treatment of process water at a laboratory in Oildale, California
- Treatment of wash water effluent at a car wash - the effluent reportedly meets the pretreatment water standards for Santa Clara, California
- Treatment of wash rack waste water in Ventura, California
- Treatment of storm water runoff in order to meet National Pollution Discharge Elimination System (NPDES) regulations in Houston, Texas

Disclaimer

Although the technology conclusions presented in this report may not change, the data have not been reviewed by EPA Risk Reduction Engineering laboratory Quality Assurance personnel.

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